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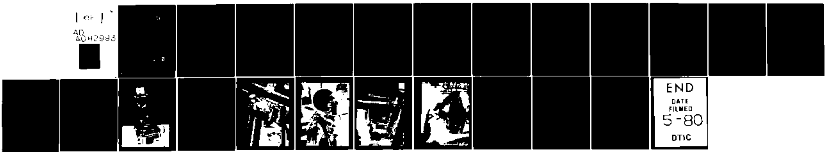

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LEVEL II

LIVE SUBJECT EJECTION TOWER TESTING TO DETERMINE HUMAN TOLERANCE TO AN INCREASED ONSET RATE OF ACCELERATION

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The U. S. Navy development of an advanced Minimal Envelope/Weight (MEW) ejection seat under the auspices of AIR-340, Naval Air System Command (NASC), had as one of its design goals the development of a pure rocket motor as the propulsion system. The finalized propulsion unit produced an acceleration onset of 500 G/sec which exceeded the specification maximum onset rate of 250 G/sec. As a consequence, this study was

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generated to determine whether the higher onset in combination with a 10 to 12 G acceleration was physiologically acceptable. This report describes the tests conducted in exploration of physiological acceptability of this particular acceleration envelope. The results indicate successful tolerance based on limited exposure of four volunteer subjects.

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SUMMARY

INTRODUCTION

Development of a MEW ejection seat was sponsored by AIR-340B as an advanced technology to overcome the various problems associated with current escape systems used in Naval aircraft (1). One area of potential improvement involved the design of a unique propulsion system. The propulsion unit developed by NWC (Naval Weapons Center) consisted of a spherical rocket motor which replaced the conventional catapult/rocket combination found in most current ejection seats. Among other advantages, the pure rocket propulsion system reduced the system weight by eliminating the catapult, its cartridges and sequencing mechanisms, while providing additional space between the guide rails for redistributing other seat components.

The rocket motor finally developed and fabricated produced a minimum 500 G/sec and a peak acceleration plateau at the 10 to 12 G level, which exceeds the currently specified physiological limit for onset. This study was undertaken to determine whether the specified onset limit could be extended for the rocket performance and remain within acceptable human subject tolerance, thereby increasing the suitability and potential of a rocket motor as a propulsion unit. This report describes the testing accomplished using anthropomorphic dummies and human subjects. It describes the catapult development to simulate the rocket acceleration profile and restraint systems used to protect the subjects.

SUMMARY OF RESULTS

Since this test program would expose human volunteer subjects to acceleration onsets beyond currently acceptable limits, SECNAV (Secretary of the Navy) permission was required to exceed 250 G/sec onset. This permission was requested (2) and subsequently granted and approved (3).

A total of 170 ejections (119 ballasted and 51 human subjects) were conducted on the NAVAIRDEVCEN ejection tower located at the Philadelphia Naval Base to complete the program. The ballasted ejections were used to develop the required catapult/cartridge configuration, and to "tailor" the catapult/cartridge performance for each G and G/sec increment for each human subject.

The human subject test program was conducted in two phases. In Phase One a group of subjects was exposed to incrementally increased G and G/sec until a 12 G-250 G/sec plateau was reached. This phase effectively "man rated" the seat and restraint system within existing acceptable limits.

(1) Hildebrand et al 18 June 1975, Maximum Performance Ejection Seat, NAVAIRDEVCEN Report No. NADC 75040-40

(2) Commander, NAVAIRDEVCEN ltr CSSA-FJ ser 6322 of 27 Jul 1971

(3) Secretary of the Navy ltr 2 Mar 1972

In Phase Two another group of subjects was again exposed to incrementally increased G and G/sec until a 12 G - 250 G/sec plateau was reached. The subjects were then exposed to incrementally increased onsets until the peak of 500 G/sec was reached while maintaining a 10 to 12 G acceleration.

During Phase Two, a specially fitted, pre-inflated air bag and sternum pad were used to provide an active safety feature for the test subject to preclude excessive head rotation during the acceleration stroke. The program was successfully concluded in October 1972 with ejection of four subjects at the required G and G/sec level. The subjects' comments varied from "sharp pain between T2 and T6" (of 30 second duration) to "smoothest ride yet." All reports of pain, discomfort and sensations were transient and similar to comments by human subjects subjected to accelerations in many other ejection programs. Pre-and-post-test medical examinations indicated no evidence of bony abnormality or orthopedic injury or sequela.

CONCLUSIONS

1. Acceleration onset rates of 500 G/sec at the 10 to 12 G level (eyeballs down) can be physiologically tolerated by aircrewman meeting physical qualification standards for ejection.

2. The MEW as configured for these tests is acceptable for safe ejection under current Navy criteria.

3. The MEW as configured for these tests and incorporating a head and neck restraint will provide adequate safety and restraint during ejections of 10 to 12 G at 500 G/sec onsets.

4. An onset of above 300 G/sec was well tolerated during 21 tests conducted in Phase Two, Part Two (Table IV).

RECOMMENDATIONS

It is recommended that further exploration be conducted to determine the upper limits of increased onset for and in conjunction with predetermined acceleration profiles. Investigation of an optimum ejection platform configuration and restraint should be conducted concurrently. It is believed that the upper limits of acceleration and onset have not been approached based on favorable comments of the test subjects, and further, that current inadequacies in aircrew position and restraint are limiting factors to the acceptance of increased acceleration profiles.

TABLE IV

PHASE II - PART II

SUBJECT	DATE	TOWER NO.	PEAK G (1)	ONSET G/sec (2)	SUBJECTS' COMMENTS
B	9/21/72	5724	10.1	326	Typical ride
C	9/21/72	5725	8.0	349	Typical ride
D	9/22/72	5726	9.0	302	Typical ride
F	9/22/72	5727	9.6	325	Some discomfort lumbar muscle after ride
A	9/25/72	5728	9.4	325	Typical ride
B	9/25/72	5729	9.9	365	Typical ride
C	9/25/72	5730	8.9	329	Slightly harder "kick"
D	9/26/72	5731	9.5	Lost	Same as last ride
B	9/28/72	5734	10.3	396	Solid shock along spine like a stiff legged jump of 6" to the ground
A	9/28/72	5735	9.6	436	Slight muscle twinge from shoulder to buttocks both sides of spine
C	9/28/72	5736	8.9	469	Harder "kick" than before
F	9/29/72	5737	8.6	372	Painful (3)
D	9/29/72	5738	9.0	427	Smoothest ride yet
C	10/3/72	5739	10.4	439	Same as last ride
B	10/3/72	5740	9.8	487	Good ride
D	10/4/72	5741	9.9	471	Same as last ride - good
A	10/4/72	5742	11.2	467	Slight muscle strain both sides of spine - similar to other seats
E	10/4/72	5743	6.8	70	No comment - OK I guess (INDOCTRINATION)
B	10/5/72	5744	11.0	525	Sharp pain T2 - T6 - 30 Sec. duration
C	10/5/72	5745	9.7	442	Smoothest ride yet
E	10/5/72	5746	9.4	303	OK - No problems
A	10/9/72	5747	9.6	497	Like other rides - harder
D	10/9/72	5748	8.6	512	Good ride

(1) Measured by accelerometer under lid
(2) Calculated from lid acceleration trace
(3) No physical injury or sequela - four days later subject eliminated self

DISCUSSION

BACKGROUND

The MEW Program was sponsored by AIR-340B and initiated under AIRTASK No. WF41-451-402 with the goal of producing an advanced state-of-the-art ejection seat devoid of the many problems associated with current ejection seats. One of the sub-systems considered for potential improvement was the seat propulsion system. Current systems employ a combination of catapult and rocket, with complex inter-sequencing requiring periodic maintenance and cartridge replacement. The weight of a conventional propulsion system, depending on its use in a particular ejection seat, is between 30 and 65 lbs. More importantly, the long tube catapult occupies critically needed space in back of the seat which could more effectively be used to house other seat components. The spherical 7" diameter underseat propulsion system (UPS) rocket motor developed by NAVWPNSCEN weighs 13.5 lbs. and is mounted within the confines of the seat bucket with a portion, including the rocket nozzle, protruding from the bottom. By locating it in this position, the back of the seat between the guide rails, is cleared for the acceptance of the recovery sub-system and other components.

UPS, as designed, develops an onset rate of 500 G/sec and maximum acceleration of 10 to 12 G. This exceeds the allowable MIL-S-18471 limit for G onset. It therefore became necessary to explore the physiological acceptability of the increased onset rate. Permission to expose human subjects to the 12 G 500 G/sec was requested of SECNAV, and subsequently received by endorsement of Commander, NADC ltr CSSA-FJ ser 6322 of 27 Jul 1971.

DESCRIPTION OF TEST

A total of 170 ejection tests were conducted on the (NDC)(CSD) vertical ejection tower located at NAEC Philadelphia Naval Base. Of these, 119 were conducted to obtain the required catapult/cartridge configuration for each subject's incremental increase in onset. In September 1971 the total live subject program was divided into two phases.

Phase One planned to expose a group of four human volunteer subjects to incrementally increased G and onset until the limits of 12 G @ 250 G/sec were reached. Approaching these peak accelerations was made very carefully, since the seat/restraint system had never been "live tested" before. Of the four volunteers who started Phase One, two were eliminated at low G levels. One subject (Subj. J) eliminated himself and the other (Subj. K) was eliminated because of suspected congenital problems with his spine. No significant data was obtained from the tests involving these two subjects. The other two subjects were successfully exposed to the 12 G, 250 G/sec onset level (Table I).

Phase Two was initiated in July 1972. A larger number of volunteer subjects were recruited than necessary to meet the program requirements. The rationale being that some subjects would be withdrawn during the program, which

TABLE I

PHASE I - PART I

SUBJECT	DATE	TOWER NO.	PEAK G (1)	ONSET G/sec (2)	COMMENTS
J	9/10/71	5580	5.5	40	
B	9/10/71	5581	4.9	40	
K	9/10/71	5582	5.4	46	
B	9/30/71	5583	4.4	36	
J	9/30/71	5584	5.0	33	
J	10/18/71	5585	5.0	33	
A	10/18/71	5586	4.3	34	
A	10/20/71	5587	7.0	66	
A	10/22/71	5588	*8.3	88	General comments by
A	10/26/71	5589	9.2	97	both subjects indi-
A	10/28/71	5590	9.9	113	cated "good ride"
A	11/2/71	5591	11.7	125	"no problems"
A	11/5/71	5595	11.5	247	
B	11/5/71	5596	6.8	64	
A	11/11/71	5597	12.4	257	
B	11/12/71	5598	8.2	96	
B	11/19/71	5599	9.7	102	
B	11/22/71	5600	11.4	168	
B	11/24/71	5601	12.5	290	

(1) Measured by accelerometer under "lid"
(2) Calculated from catapult pressure trace
*   Lid trace lost - estimated from catapult trace

later proved to be a valid assumption. Eight volunteer subjects were enlisted for completion of Phase Two. All new subjects were indoctrinated on the tower and started up the "ladder" of acceleration exposure in an attempt to reach the plateaus attained in Phase One. Of this group, one withdrew, one was eliminated because of involvement in auto accident, and one contracted mononucleosis before starting the onset increases. One additional subject requested participation in the program after the tests had begun, but was eliminated because of scheduling conflicts with his other duties (Subj. E). Data for these tests is reported in Table II since they were preliminary to the start of increasing the onset beyond 250 G/sec. Tests 5680 through 5691 in Table II may appear redundant. However, these tests were made in an attempt to develop an optimum location/configuration for the head restraint (air bag), and to evaluate its effectiveness. Two subjects (A and H) with extremes in anthropometry (see Table III) ejected at low G with the head positioned forward, in a deliberate attempt to induce a controlled head rotation at a low G level. When a maximum head rotation was reached, the air bag was placed under the subject's mandible and reduction of head rotation was measured. The safety and confidence gained from the use of the air bag was an unquestionable benefit in completion of the program without nuchal injury. In September 1972 the first controlled increased onset ejection test was made using a live test subject. Subsequently, 23 live subject ejection tests were conducted to complete the program objective and are shown in Table IV.

SEAT DESIGN, MODIFICATIONS AND RESTRAINTS

The MEW seat structure is basically aluminum honeycomb sandwiched in skins of aluminum sheet. An integral mounting pad is provided under the bucket structure for attachment of a spherical rocket motor. A 3/8" thick, contoured aluminum honeycomb "lid" is mated to the bucket to provide the ejection platform. Hard-point connections are provided for attachment of lower and upper restraint fittings. A one-piece vertically adjustable head rest is mounted to the seat back.

A lap belt (Ref. P/N AN7507) was used for lower torso restraint. Two lengths of nylon webbing were attached to the upper seat connection for shoulder restraint. The upper Koch fittings of the standard MA2 harness were reversed to allow for adjustment on the upper seat webbing, in lieu of on the harness because there was no inertia reel mounted on the seat for these tests. A "DEE" ring was affixed to the front of the seat bucket to permit the subject to initiate his own ejection. A comfort cushion of 1/2" thick cored foam rubber (MIL-R-5001) was covered with nylon cloth and attached to the lid with velcro tapes. A sheet of 1/2" thick ensolite was bonded to the back of the seat for positioning and comfort (Figure 1).

TABLE II

PHASE II - PART I

SUBJECT	DATE	TOWER NO.	PEAK G (1)	ONSET G/sec (2)
H	7/25/72	5680	4.4	34
A	7/25/72	5681	5.2	39
A	7/27/72	5682	5.1	45
H	7/27/72	5683	4.5	29
A	8/1/72	5684	7.2	66
H	8/1/72	5685	7.2	63
H	8/3/72	5686	7.7	78
A	8/3/72	5687	8.3	89
H	8/11/72	5695	8.7	74
H (3)	8/24/72	5701	11.9	254
C	8/24/72	5702	9.9	100
G	9/6/72	5713	12.4	245
C	9/6/72	5714	11.5	261
D	9/11/72	5715	7.2	67
F	9/11/72	5716	6.4	55
I	9/13/72	5717	7.3	87
D	9/13/72	5718	10.2	98
F	9/13/72	5719	10.1	102
F	9/18/72	5720	11.6	219
D	9/18/72	5721	11.0	211

(1) Measured by accelerometer under "lid"
(2) Calculated from "lid" acceleration trace
(3) This and all subsequent live subject ejections employed an "air bag" as a protection against head and neck injury.

TABLE III

SUBJECT ANTHROPOMETRY

	SUBJECT	WEIGHT LBS.	HEIGHT IN.	SHOULDER HEIGHT	SITTING HEIGHT
A	HM1 MacCoy	140	67.0	25.0	35.3
B	HM3 Miller	132	69.0	23.8	37.8
C	HM1 Remsen	198	70.5		36.0
D	Fisk	195	70.0	25.7	37.2
E	Hatley	165	68.1	25.3	36.5
F	Stair	157	68.2	24.5	36.4
G	Andersen	137	65.1	24.8	35.4
H	Karge	172	76.3	26.9	40.0
I	Cospelich	240	*	*	*
J	Destler	189	*	*	*
K	Skelton	176	*	*	*

* Not obtained - Anthropometer not available

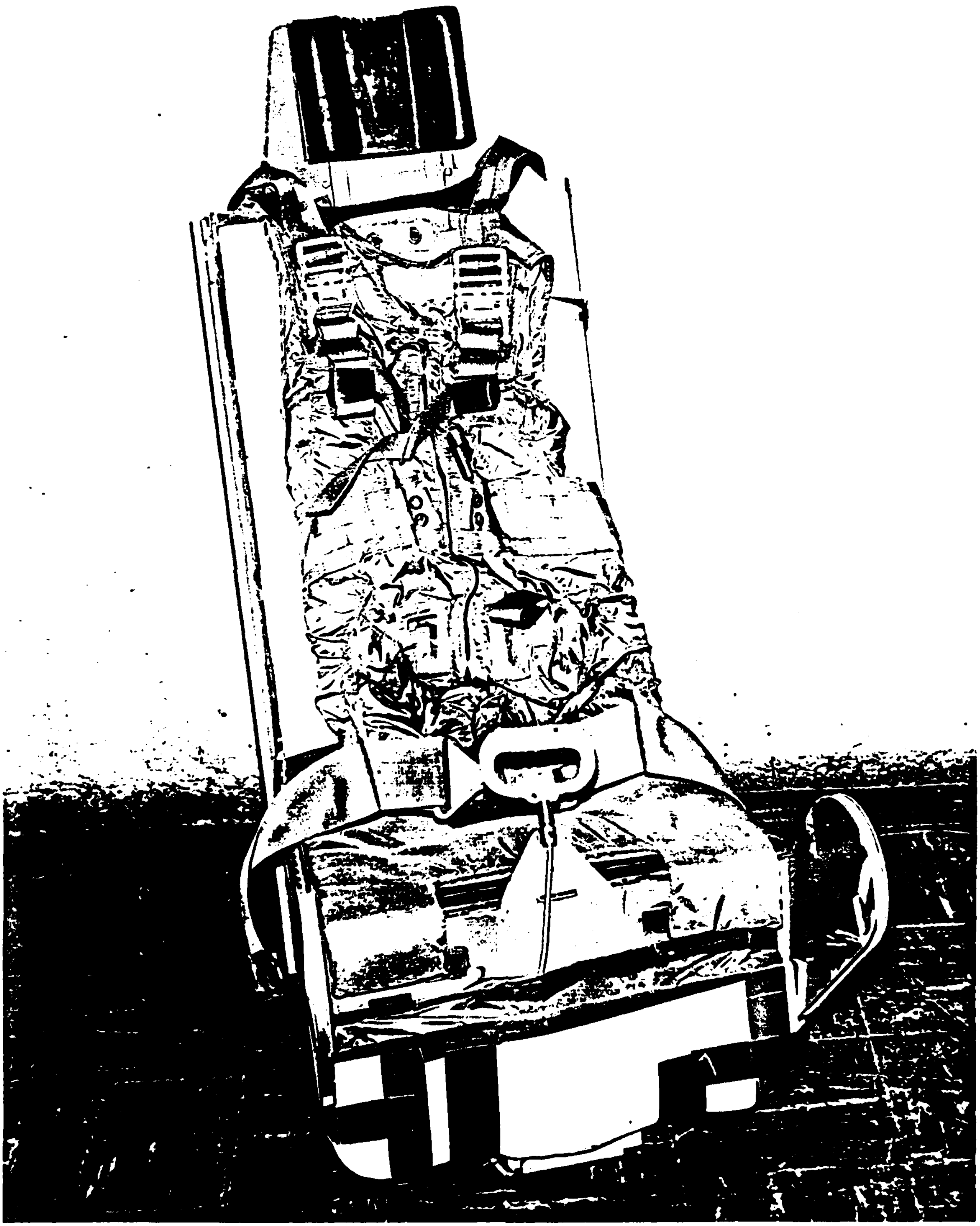


FIG. 1

SUBJECTS' GARMENT MODIFICATIONS

All human subjects engaged in this program were personally fitted for optimum restraint with an MA2 torso harness. To standardize procedures and to facilitate adjustment of the shoulder restraint, the male halves of the Koch quick release fittings (P/N 015-10307-5) were removed from the upper harness webbing and replaced by the female halves (P/N 015-10968-1). The female halves were then sewn securely in place on the torso harness webbing. One pair of the male fittings (containing the adjuster) was then reeved to the seat restraint webbings (Figure 2). Each subject wore a stripped APH-6 helmet, individually fitted. During Phase Two a velcro strip was added to the rear of the helmet and a head restraint air bag was attached and then positioned under the subject's mandible (Figure 3). Each subject also wore an individually fitted "breast plate" of ensolite cushioning material to fill the void between the air bag and the sternum. This was done in an effort to prevent head rotation rather than to minimize or absorb the energy of head rotation. Ensolite pads were placed under the upper Koch fittings to reduce chafing from repeated ejections. One subject had a special lumbar pad fitted to the seat for comfort and lumbar support (Figure 4). Selectively located foot rests were provided for optimum pre-ejection leg positioning. During Phase One tests, no external head restraint was used. However, by constant analysis of motion film coverage obtained during the G build-up ejections, the head rest was relocated to minimize head rotation. In addition, each subject was instructed to make a conscious effort to keep his head from rotating. With all these precautions, head rotation was kept at a safe level. Before each test the subject was fitted with surface electrodes for continuous monitoring of electroenco phalogram (EEG)(occipital region), electromyogram (EEG)(nuchal), and full electrocardiogram (Figure 5).

THE CATAPULT

Since the spherical rocket propulsion unit could not be used on the ejection seat tower, a NADC 40" stroke test catapult was modified to simulate the initial rise and acceleration which would be produced by the rocket. The catapult was used throughout the tests, adding propellant and manipulating the inserts and venting to obtain controlled onset and G levels. The catapult final configuration selected consisted of the forty inch stroke steel NAMC catapult with the outer tube vented to control internal combustion pressure, a MK1 MOD2 standard ejection cartridge and variable inserts to decrease combustion volume which in turn controlled onset rate. Proper location of the outer tube vents was obtained by a spacer arrangement under the outer tube which controlled the peak G levels by venting combustion pressure at the proper time.

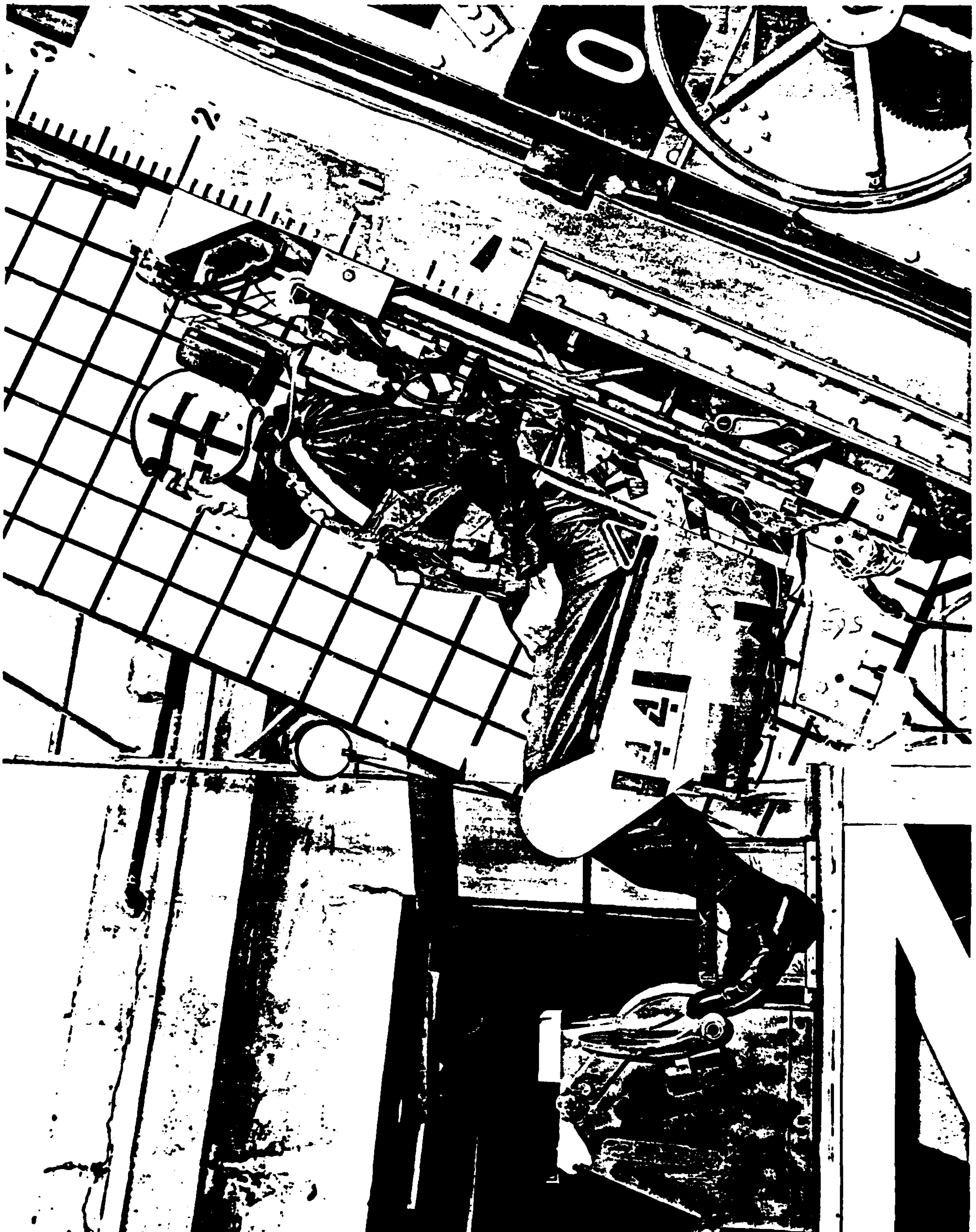


FIG. 2

FIG 3

FIG.4

FIG. 5

INSTRUMENTATION TECHNIQUES

The standard data reduction procedure used by this activity (4) for obtaining peak acceleration is to examine the recorded seat acceleration trace for peaks which are then reduced to the level sustained for 20 milliseconds. This is then identified as the maximum G. Onset (G/sec) is calculated from the catapult pressure-time trace by constructing a right triangle using the maximum pressure rise slope lasting 30 milliseconds or longer and its intersection with the peak pressure to define the triangle coordinates. The onset is calculated from:

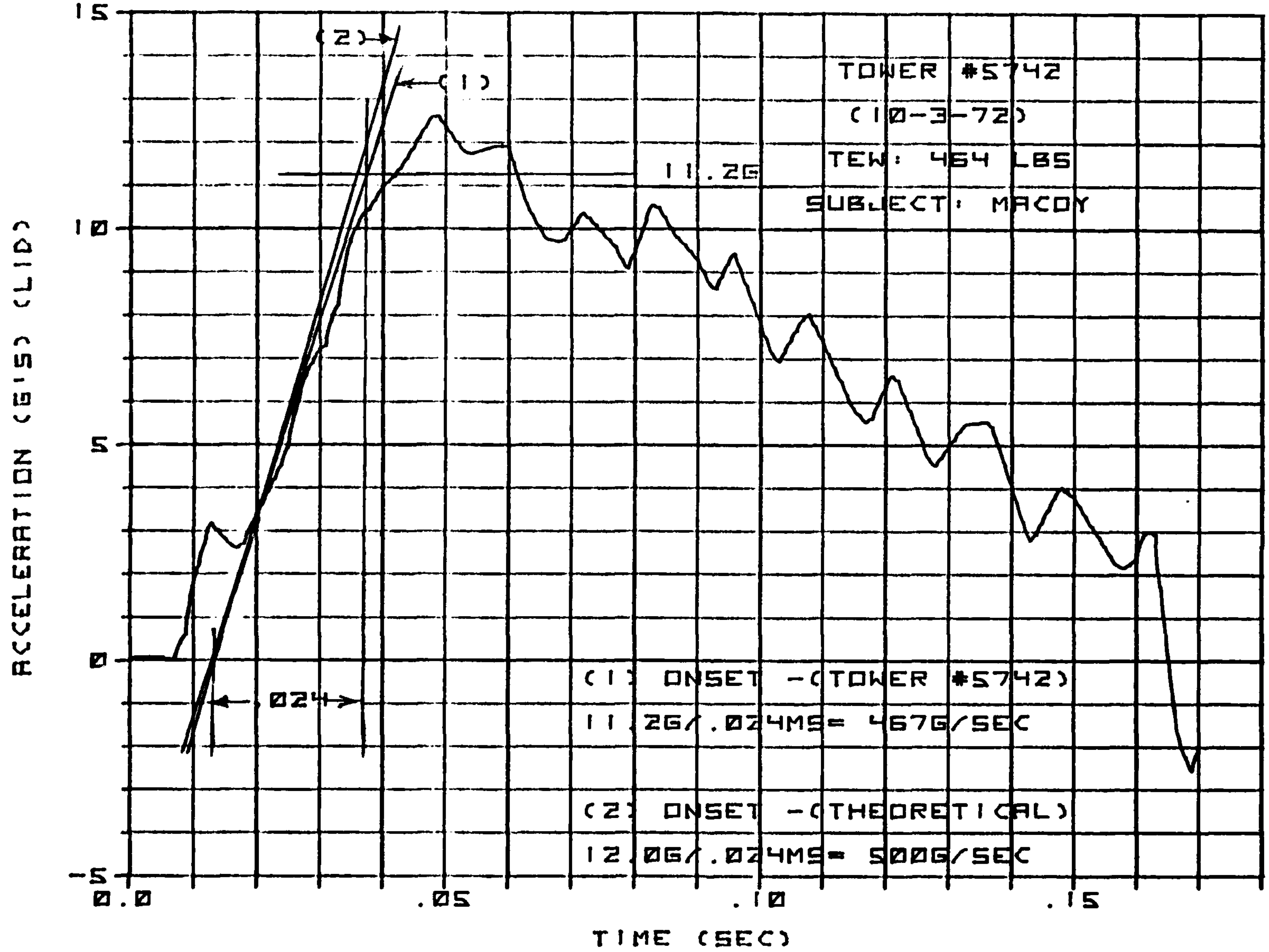
$$\text{Onset (G/sec)} = \frac{\text{Maximum Catapult Pressure X Catapult Pushing Area}}{\text{Total Ejected Weight X Time}}$$

During this program it was decided to deviate from the standard operating procedures. A theoretical onset of 500 G/sec would be completed in 24 MS at a 12 G level, precluding use of the 30 millisecond rule. An example is shown in Figure 6. It was also decided that acceleration inputs should be recorded as closely as possible to the acceleration sensed by the subject. Accordingly, an accelerometer was mounted under the ejection platform (seat lid), and used for data recording. The best fitted straight line through this acceleration trace was used to compute data for this program.

PHOTOGRAPHIC COVERAGE

High speed motion film coverage consisted of one 400 Frame Per Second (F.P.S.) Milliken to record the total ejection, and two stationary cameras viewing the left side of the seat, a 400 F.P.S. Milliken and a 1000 F.P.S. Photosonic. The motion film coverage was used for analysis of subject's restraint effectiveness and for record purposes. No data reduction was accomplished from the film.

(4) M. Schulman, ACEL Paper 15 Jan 1958, "Recommendation for Standardization of Techniques used for Analysis of Data Obtained from Escape System Tests"



TOWER #5742
(10-3-72)
TEW: 464 LBS
SUBJECT: MACOY
11.2G
(1)
(2)
.024
(1) ONSET -(TOWER #5742)
11.2G/.024MS= 467G/SEC
(2) ONSET -(THEORETICAL)
12.0G/.024MS= 500G/SEC
ACCELERATION (G'S) (LID)
15
10
5
0
-5
0.0
.05
.10
.15
TIME (SEC)

FIGURE 6

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